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A CONTINUOUS SCAN SCINTILLATION SYSTEM FOR THE INSPECTION OF TUNGSTEN BILLETS

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12ND. P7463

INSTRUMENTS BRANCH
K. F. Sinclair, Head

NUCLEONICS DIVISION
W.E. Kreger, Head

ADMINISTRATIVE INFORMATION

This report covers a facet of the work authorized during FY 1962 by the Bureau of Naval Weapons Special Projects Group. Details of this work are found in the U.S. Naval Radiological Defense Laboratory FY 62 Technical Program as Program D-1, Problem 10, entitled "Development of Nondestructive Test Methods for POLARIS," the objective of which is to support the solid propellant missile program of the Navy by: (1) developing new or modified nondestructive testing techniques, (2) examining the limitations and essential parameters of existing techniques, and (3) providing consulting services. Funds to support this work during FY 62 were provided by the Bureau of Naval Weapons on Budget Project 98, allotment 178/62.

ACKNOWLEDGMENTS

The authors acknowledge the valuable assistance of Mr. Robert Raudso, Hornbein Consulting Engineers, Inc., in the course of the work and the help of Mr. Frank X. Schoner, Aerojet-General Corporation, during the testing phase.

Eugene P. Cooper

Eugene P. Cooper
Scientific Director

E. B. Roth

E.B. Roth, CAPT USN
Commanding Officer and Director

ABSTRACT

A continuous scan system, employing a 200 curie Co^{60} source, scintillation detection of transmitted radiation, differential d.c. amplification and strip-chart recording, has been applied experimentally to the inspection of tungsten billets used in the fabrication of nozzles for solid propellant rocket motors. The results of a detailed inspection of an uninfiltrated billet, supplied during the first phase of a round robin among a manufacturer and several Navy laboratories, were in agreement with radiographic data obtained during an earlier inspection. With this billet, the volume sensitivity of the system was measured to be about 5.0×10^{-2} cm^3, which was within a factor of two of the predicted sensitivity of 2.7×10^{-2} cm^3. The experimental work showed the feasibility of the continuous scan method as a primary inspection method for the inspection of tungsten billets and clearly demonstrated its usefulness in the present state of development as a supplement to film radiography.

SUMMARY

THE PROBLEM

To determine the performance capability of the continuous scan scintillation method for the inspection of tungsten nozzle billets during the first phase of a round robin inspection of selected billets. (See Appendix.)

THE FINDINGS

The results of the inspection of one uninfiltrated billet with an experimental system showed the feasibility of the method as a primary inspection technique and clearly demonstrated its present usefulness as a supplement to film radiography.

INTRODUCTION

A high level of quality control is required in all phases of fabrication of tungsten nozzles for rocket motors. Beginning with the forming of a suitable billet, its subsequent infiltration, and throughout the machining operations, NDT (nondestructive testing) must be used to determine the surface and internal condition of the piece. In addition to defects such as cracks and voids, density variations which are indicative of unsatisfactory porosity, inadequate infiltration of silver, or possible internal stress must be detected. These variations may be abrupt density discontinuities of less than 1 percent or more gradual changes of several percent.[1]

A number of inspection tools are now being used in this application.[2] Although film radiography is the principal method employed, ultrasonic, dye penetrant, and eddy current methods are used also. However, the thick sections and high density of the billets, the porosity which exists before infiltration, and the rough surfaces of unmachined billets limit the usefulness of some of these methods or necessitate special techniques. For example, porosity precludes immersion of the uninfiltrated billet, without a protective covering, into a fluid for ultrasonic inspection; also, the dye penetrant and eddy current methods generally are useful for surface inspection only, the dye penetrant method being limited to pieces which are infiltrated and no longer porous and the eddy current method to machined surfaces. Because of these limitations and the variations in methods and techniques actually employed, inspection results generally are difficult to correlate and interpret in practice.

In order to compare test methods and techniques now being used and to establish optimum or improved inspection methods for tungsten nozzle NDT, a round robin of testing of specially treated billets has been initiated among several of the naval laboratories and the Aerojet-General Corporation as a part of the Polaris Program. (See Appendix.) This effort will include the study of new NDT methods or existing methods not currently used in the inspection of tungsten billets.

During the first phase of the round robin, this Laboratory constructed and tested an experimental inspection system for this application, using a 200 curie Co^{60} source and a scintillation detector. Although the method used is not new,[3,4] it had not been applied previously to the inspection of tungsten billets. The results clearly demonstrated the usefulness of the method in its present state of development as a supplement to film radiography.

This report describes the approach taken in the design and fabrication of the experimental system and relates the results of measurements made on an uninfiltrated billet to the practical application of the method.

APPROACH

Three billets in the form of thick-walled hollow cylinders, together with several tungsten penetrameters, were furnished in the first phase of the round robin. These billets were approximately 10 in. OD, 4 in. ID, and from about 6 to 9 in. high. Two of the billets were uninfiltrated. The one sound billet provided was uninfiltrated. (See Appendix.)

Since the principal objective was to examine feasibility, the approach taken was to construct an experimental scan system and to examine in detail at least one of the cracked billets. Uninfiltrated billet AG2231 was selected to simplify the analysis and inspection, which otherwise would be complicated by the presence of silver in the infiltrated billet. (Consideration will be given to infiltrated billets during the second phase of the round robin when billet AG2231 will be infiltrated.)

Use of the transmitted radiation method (source and detector on opposite sides of the test piece) was clearly indicated in this application. However, an analysis was required to establish the best system design possible with the sources and components readily available in the Laboratory.

PERFORMANCE CRITERIA

Criteria for the general performance of continuous scan systems, employing the transmitted radiation method, have been established[3,4] and can be applied directly. From these criteria, volume sensitivity (V) can be predicted for a selected source, detector size and arrangement, collimator aperture, and scan speed:

$$V = \frac{k}{\mu}\left(\frac{h\ v_s}{f\ E}\right)^{1/2} \tag{1}$$

where

μ = linear absorption coefficient (cm^{-1})

h = collimator aperture height (cm)

v_s = scan speed (cm/sec)

f = photon flux at detector (photons/cm^2/sec)

E = detector efficiency (fractional)

and

k = constant

= 3.14 for two-detector differential system

= 2.21 for one-detector system.

This expression assumes that the flaw is detected with 95 percent confidence and that the system time constant (T) is optimum:

$$T = \frac{t}{1.37}$$

where $t = \frac{\ell}{v_s}$ = time for flaw to traverse collimator aperture (sec)

and ℓ = collimator aperture length (cm).

DETECTOR DESIGN

Two basic detector configurations can be employed; the two-detector differential system, and the one-detector system with differential d.c. bias. The principal difference in the two configurations is the automatic compensation provided by the former arrangement for thickness or density variations over areas which are large with respect to the collimator aperture area, thus optimizing system performance for cracks or discontinuities falling within the aperture. Since it was desired to inspect for gradual density variations as well as for cracks, the one-detector system was used.

In addition, the detector can be located in one of two ways: (a) outside the billet, thus requiring transmission through the entire diameter or length of the cylinder; and (b) in the cylinder hollow. The former location has the advantage of easy access to the detector for scanning and simplifies the shielding of the detector. However, locating the detector in the cylinder hollow has the advantage of increasing the available flux at the detector, and thus the sensitivity, by several orders of magnitude, even for relatively high energy sources. Therefore, the geometry shown in Fig. 1 was selected.

To improve resolution and provide maximum shielding for the detector within the cylinder hollow, a crystal 1/2 in. in diameter and 3/4 in. in length was used in conjunction with a 3/4-in. diameter multiplier phototube. The lead shield and detector remained fixed, while the billet was rotated about it. By elevating or lowering the billet after each complete rotation, the major portion of the billet was scanned.

SOURCE SELECTION

It has been shown[3,4] that the relative S/N (signal-to-noise) of the system is related to source energy in the following manner:

$$S/N \propto \mu e^{\frac{-\mu x}{2}} \qquad (2)$$

where

x = thickness of test piece (cm).

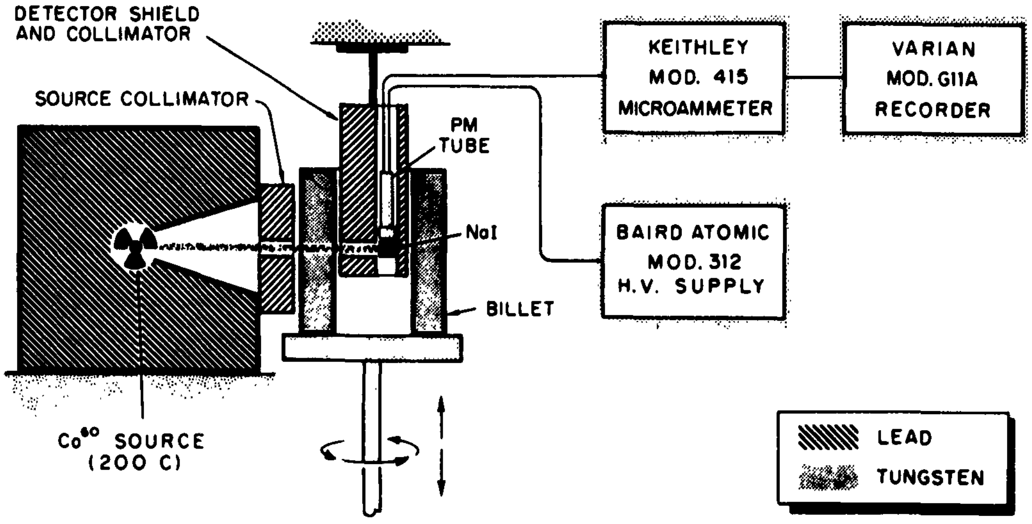


Fig. 1. Simplified Diagram of Experimental Scan System for Tungsten Billet Inspection

Uninfiltrated billet AG2231 consisted of 80 percent density tungsten and had a wall thickness of 7.94 cm. An examination of equation (2) as a function of source energy for this billet showed optimum S/N to correspond to 3.0 - 4.0 Mev. However, Co^{60} was selected as the source because of its availability.

Relative S/N as a function of source energy up to 10.0 Mev is plotted in Fig. 2. At 10.0 Mev, S/N falls about 20 percent from the optimum; and at Co^{60} energy, S/N drops more than 40 percent. Although equation (2) does not consider detector efficiency, the difference in efficiency between Co^{60} energy and 4.0 Mev would be less than about 2 percent.[5] Therefore, as a result of using Co^{60}, the over-all sacrifice in S/N was estimated to be about 40 percent of the optimum.

COLLIMATOR APERTURES

The aperture of the detector lead collimator was arbitrarily selected to be 3/4 in. x 3/4 in., approximating the dimensions of the crystal. Since the detector collimator was limited to a thickness of about 2 in., an additional lead collimator of 4 in. thickness and with an aperture of 1.0 in. in diameter was provided at the source to improve resolution.

SCAN SPEED

The scan speed was set by the period of rotation of the available rotating table which was 250 sec/rev. Therefore, the scan speed for a point on the outside surface of the billet was 0.336 cm/sec and on the inside surface, 0.136 cm/sec.

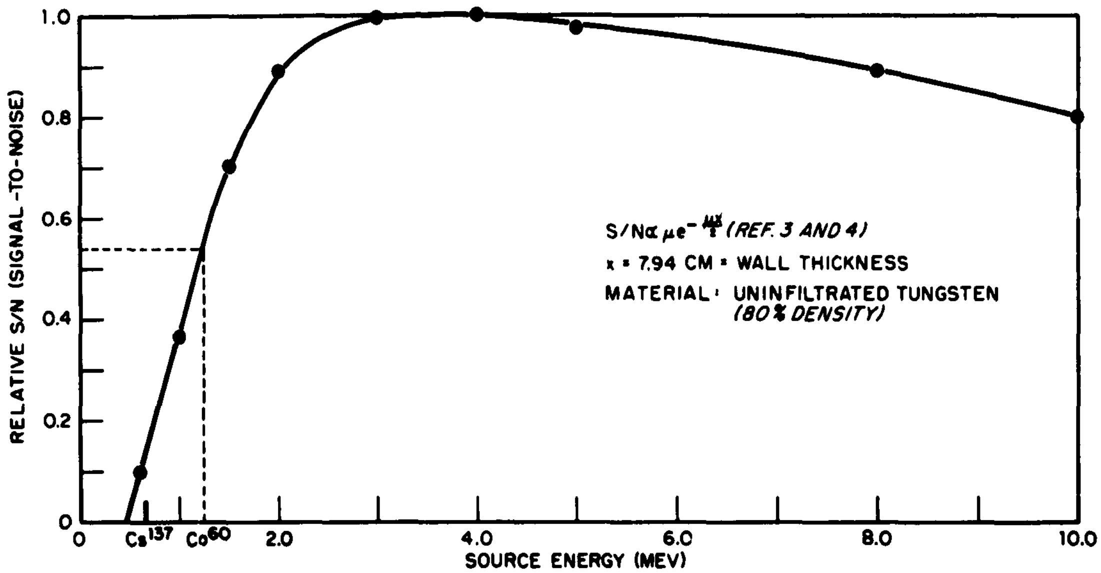


Fig. 2 Relative S/N vs Source Energy for Tungsten Billet AG2231

FLUX AT DETECTOR

The 200 curie Co^{60} source used provided 500 r/hr at the detector with the billet removed. With the billet in place, the intensity at the detector was 0.85 r/hr, corresponding to a flux of about 3.8×10^5 photons/cm^2-sec.[6]

FINAL SYSTEM DESIGN

The final design of the system is shown schematically in Fig. 1 and in the photographs of Fig. 3.

PREDICTED SENSITIVITY

From expression (1), the volume sensitivity at the center of the billet wall was predicted to be 2.25×10^{-2} cm^3. The sensitivity was estimated to be about 20 percent lower on the outer surfaces of the billet and about 30 percent higher on the inner surface because of the higher scan speed on the outer surface and the lower scan speed on the inner surface.

RESULTS

Billet AG2231 was scanned in eight 1/2-in. steps beginning 1-3/4 in. from the machined end of the billet and ending 5 1/4 in. from that end. The traces obtained and a summary of an interpretation of each trace are shown in Fig. 4.

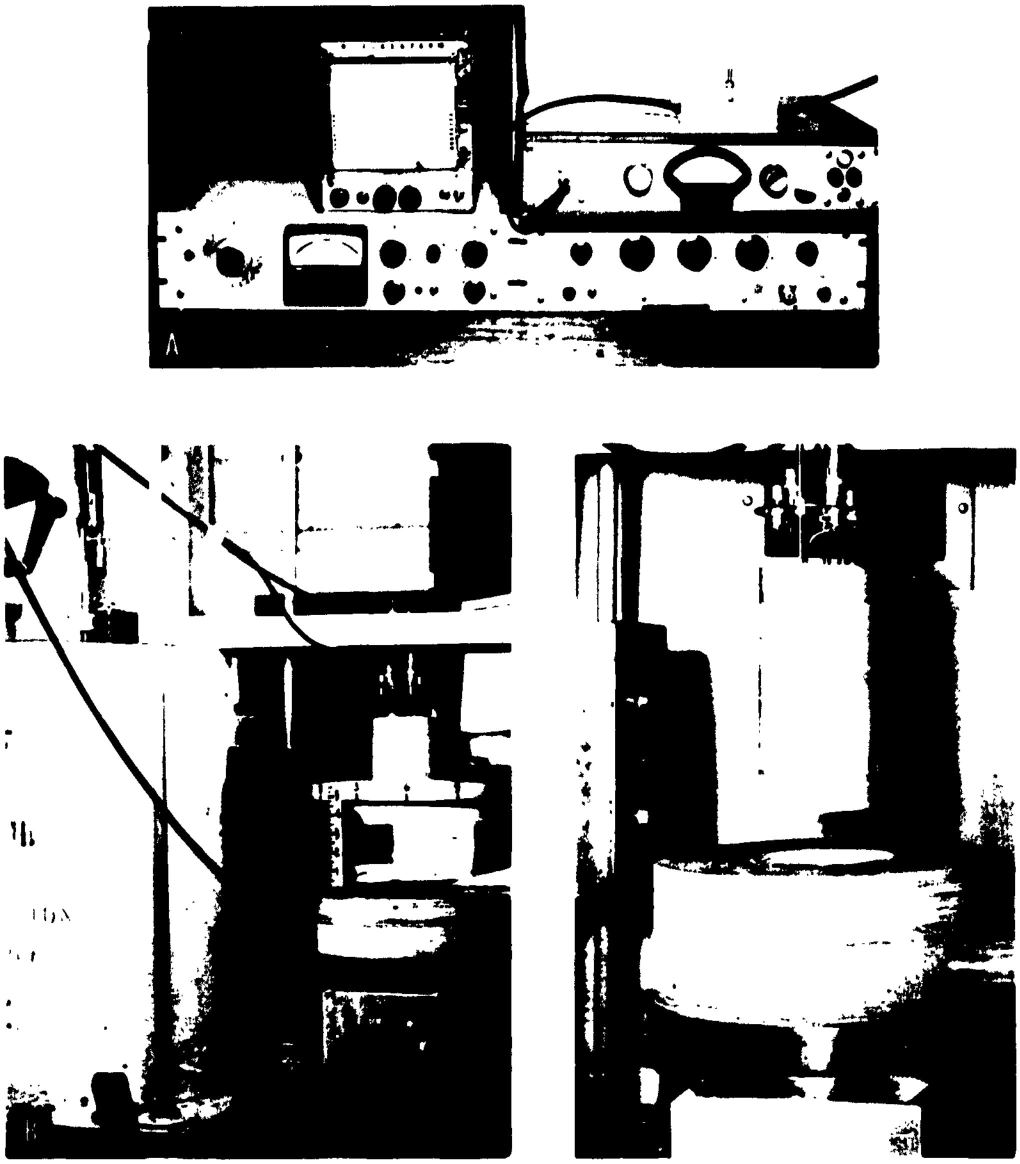
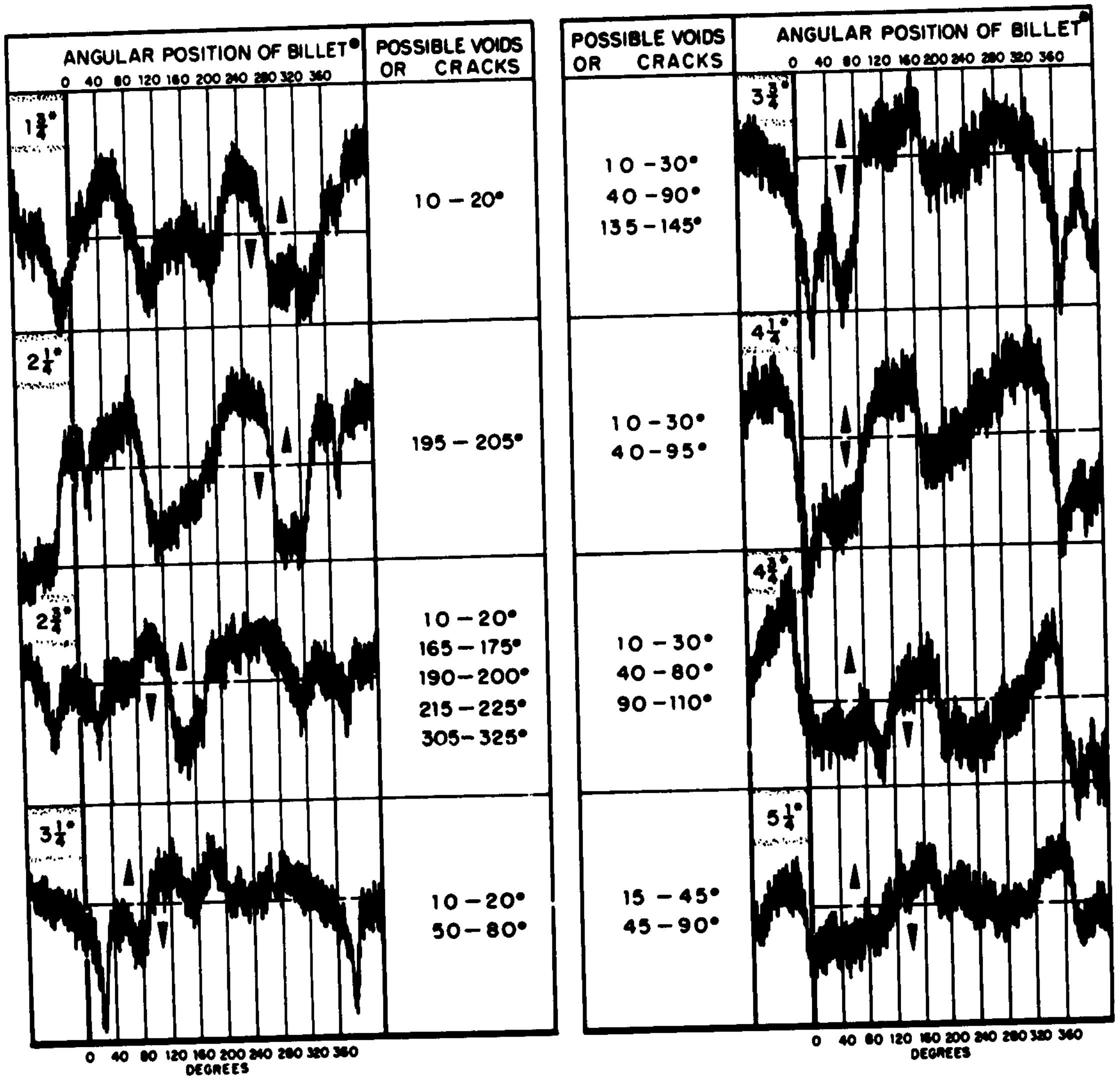


Fig. 3 Experimental Scan System for Tungsten Billet Inspection
A. Microammeter, Recorder, and HV Supplies
B. CO^{60} Source, Rotating Table, Detector, and Tungsten Billet
C. Billet Removed to Show Detector and Collimator



• AEROJET GENERAL CORP. MARKINGS

• DISTANCE FROM CENTER OF NaI CRYSTAL TO MACHINED END OF BILLET (INCHES)

▲ HIGH DENSITY RELATIVE TO AVERAGE OF INDIVIDUAL SCAN

▼ LOW DENSITY RELATIVE TO AVERAGE OF INDIVIDUAL SCAN

Fig. 4 Results of Tungsten Billet AG2231 Inspection

A complete inspection of the billet over 3 1/2 in. of its length required about 40 minutes. Several successive inspections were made to evaluate the reproducibility of the measurements. Although the average level of equivalent points on the recorder traces for successive scans varied by as much as ± 20 percent in amplitude, the presence of density variations and of voids or flaws was clearly indicated in repeated inspections. Almost all of the amplitude variation observed was attributed to the instability of the multiplier phototube and d.c. amplifier.

The traces were then compared with film radiographs provided by the Aerojet-General Corporation, Sacramento, California, and were found to correspond closely with the film readings.[2] In one instance, a subtle density change not indicated by the film was shown by the scanner trace and subsequently confirmed when the film was re-examined.

The sensitivity of the system was checked, using the 0.060 in. thick tungsten penetrameter (100 percent density) provided. From successive measurements, volume sensitivity (for 95 percent confidence) at the surface of the billet was estimated to be about 5.0×10^{-2} cm^3, which was in fair agreement with the predicted value of about 2.7×10^{-2} cm^3 in view of systematic noise (not considered by equation (1)) and the fact that the system time constant (T) was somewhat less than the optimum value.

CONCLUSIONS AND RECOMMENDATIONS

The tests made clearly showed the usefulness of the continuous scan method as a supplement to radiography. The strip-chart record presented an objective and immediate indication of the condition of the billet for each scan interval along its length at a sensitivity comparable to film radiography. More detail for each defect area indicated by the record could be obtained from the film radiographs which provided a much higher resolution.

In its present state of design, the scan system used is a practical inspection means, offering at moderate cost rapid examination with relative simplicity and ease of operation. Its principal limitation is in resolution. However, both resolution and sensitivity of the experimental system can be improved greatly without appreciably increasing inspection time or cost. This improvement would come principally from the selection and design of the source and source holder. For example, by reducing the collimator aperture height (h) and length (ℓ) by 50 percent to 3/8 in. x 3/8 in. and doubling both scan speed (v_s) and photon flux (f) at the detector, system resolution would be improved by a factor of 4 while increasing volume sensitivity (V) by about 30 percent. (See equation (1).) Even with the present source strength of the experimental system, the photon flux at the detector could be doubled easily by the use of a source holder which would reduce the source-detector distance from the present 50 cm to about 30 cm. Although more expensive, machine sources having energies above 2 Mev offer additional alternatives.

The strip-chart readout used in the experimental setup was generally satisfactory, but it was difficult to correlate the eight 1/2-in. step scans to establish the condition of the billet for a 3 1/2 in. long section at a specific angular position. This difficulty stemmed principally from the lack of a standardized level to which all scans could be referred. However, such a reference level can be provided by a number of methods, one of the simpler being through the use of a "standard block" approximating the normal billet thickness. The standard block would be measured at predetermined intervals during the inspection and the system gain standardized either manually or automatically. The same approach can be applied to the inspection of tapered billets. In addition to standardizing system gain, the d.c. reference bias at the differential input would be adjusted to correspond to the thickness along the tapered length of the billet.

The mechanical design of the system does not pose any significant problems. Several alternatives exist for the positioning and scanning of the billet. For example, the rotational scan pattern which has been described can be used with the longitudinal axis of the billet in a horizontal rather than a vertical plane to allow better access to the detector, which in some applications may be a two-detector assembly. In addition, for either position of the billet, it can be scanned along its length and indexed by rotation at the end of each scan. This scan pattern, as opposed to the rotational pattern, has the advantage of providing a uniform flaw sensitivity throughout the thickness of a cylindrical billet, since the scan speeds of both the inner and outer surfaces of the piece are the same. However, the rotational pattern is more suitable for the inspection of tapered billets, since each rotational scan is presented with a uniform cross section.

Of the inspection geometries possible for the cylindrical billet, the one used in these tests (Fig. 1) is the most useful in detecting defects and most density changes. However, density changes which have uniform cylindrical symmetry may not be detected in the geometry of Fig. 1. Ideally, the billet would be scanned through its end and with the source-detector axis paralleled to the axis of the cylinder to detect such density changes. It can be seen that this geometry has the disadvantage of requiring transmission through a length of tungsten which is two or three times the wall thickness examined in Fig. 1, thus greatly reducing the sensitivity of this method or of the radiographic methods. However, since the density condition described can be detected by one or two end scans of the cylinder wall along a radius, scan speed (v_s) can be greatly reduced to provide adequate sensitivity yet to maintain a reasonable inspection time.

Although the system described does not achieve the resolution of film radiography, it does equal or exceed the film sensitivity. In addition, it offers means for automatic or semiautomatic inspection through the use of "go" or "no go" limits applied to the system output. Also, this method will compare favorably with the ultrasonic technique in resolution, sensitivity and cost, and it will offer the advantages of greater simplicity in operation and ease of interpretation of results, especially for the inspection of uninfiltrated billets. Therefore, it is felt that further development to increase sensitivity and resolution of the continuous scan scintillation method and to improve readout techniques is warranted, with the objective of providing a new primary inspection tool for tungsten billets.

APPENDIX

SILVER-INFILTRATED TUNGSTEN ROUND ROBIN[2,7] INSTRUCTIONS AND SCHEDULE - PHASE I

1. Parts

Aerojet-General Corporation Serial No.	Density g/cm^3	Description
AG2230	16.31	Sound, uninfiltrated, tapered billet; max dimensions, 9 1/2 in. OD x 3 1/2 in. ID x 9 1/2 in. L
AG2231	15.20	Cracked, uninfiltrated, symmetrical billet; dimensions, 10 1/2 in. OD x 4 1/4 in. ID x 5 3/4 in. L
AG2232	15.49*	Cracked, infiltrated, symmetrical billet; dimensions, 9 1/2 in. OD x 3 7/8 in. ID x 6 1/4 in. L

2. Investigation Schedules

Each laboratory shall have approximately two weeks of investigation time and shall ship the material to the next laboratory on or before the date listed below:

Laboratory	Approximate Receiving Date	Required Shipping Date
ACC, Sacramento, Calif.	---	6-9-62
NAD, Concord, Calif.	6-17-62	6-30-62
NRDL, San Francisco, Calif.	7-8-62	7-21-62
NOL, White Oak, Md.	8-5-62	8-19-62
NRL, Washington, D.C.	8-26-62	9-8-62

*Before infiltration

The last named laboratory, (NRL, Washington, D. C.) shall ship the uninfiltrated billets, AG2230 and AG2231, for infiltration, to:

Firth Sterling, Inc.
McKeesport, Pennsylvania

Attn: B. A. Backstrom

The remainder of the material shall be returned to:

Aerojet-General Corporation
Solid Rocket Plant
Nimbus, California

Bldg. 2004, Attn: F. X. Schoner

3. Calibration Standards

Included with the shipment shall be the following drilled standards:

a. One 3 1/4 in. dia. x 5 3/8 in. long uninfiltrated billet containing a 1/8 in. dia., 1/2 in. deep flat bottom hole in one end and a 1/8 in. dia., 1/2 in. deep flat bottom hole drilled radially.

b. One section of infiltrated billet, 5 3/8 in. long, 3 1/8 in. thick, containing three flat bottom holes, each 1/2 in. deep and 3/64 in. and 1/8 in. diameter.

c. Part AG2232 contains three flat bottom holes drilled in the unmachined end, each 1/2 in. deep and 3/64 in., 5/64 in. and 1/8 in. diameter, respectively.

4. Purpose of Investigation

The tests shall be directed toward determining the following properties of the tungsten:

a. Uninfiltrated billets.

(1) Measurement of density variations.

(2) Determination of grain size, surface and subsurface.

(3) Detection of surface cracks, and porosity.

(4) Detection of subsurface inclusion, cracks, and porosity.

Caution: Uninfiltrated materials <u>may not</u> be immersed in any fluid nor shall any fluid be used on the surfaces. Contamination will retard subsequent infiltration with silver.

b. Infiltrated Billets:

(1) Measurement of density variations.

(2) Determination of grain size, surface and subsurface.

(3) Detection of surface cracks, and porosity.

(4) Detection of subsurface inclusion, cracks, and porosity.

(5) Determination of effectiveness of silver infiltration.

5. Methods of Investigation

The nondestructive tests to be performed at each laboratory shall consist of the following:

a. X-ray examination.

b. Ultrasonic examination.

c. Eddy current tests.

d. Density determination.

e. Penetrant inspection (on infiltrated billet only).

f. Any additional techniques the testing laboratory may develop.

Caution: No penetrant inspection is to be performed on uninfiltrated billets.

6. Test Reports

Reports of the results of the nondestructive tests performed shall be forwarded to the Bureau of Naval Weapons and to the Aerojet-General Corporation:

a. SP 271
b. SPL40
c. SP27112
d. SPLA40
e. J. A. Hendron, AGC, Sacramento

7. <u>Future Tests</u>

In addition to Phase I, the following investigations are to be included in this Tungsten Round Robin:

a. Phase II - NDT of Billets AG2230 and 2231 after infiltration with silver.

b. Phase III - NDT of two uninfiltrated billets, one containing voids of various sizes and one containing variable density conditions.

c. Phase VI - NDT of the two billets mentioned in 7.b after infiltration with silver.

Future instructions will be forthcoming when these pieces are made available.

8. <u>Addresses of the Participating Laboratories</u>

a. Aerojet-General Corporation
Solid Rocket Plant
Nimbus, California

Bldg. 2004, Attn: F. X. Schoner

b. Commanding Officer
Naval Ammunition Depot
Concord, California

Quality Evaluation Laboratory
Attn: Frank Hund

c. Commanding Officer and Director (Code 942)
U.S. Naval Radiological Defense Laboratory
San Francisco 24, California

Attn: Kenneth Sinclair

d. Commander (Code 422)
   Naval Ordnance Laboratory, White Oak
   Silver Spring, Maryland

   Attn: Edward Criscuolo

e. Director (Code 6254)
   Naval Research Laboratory
   Washington 25, D.C.

   Attn: Stephen Hart

REFERENCES

1. "Infiltrated Tungsten; Billets and Preforms - Polaris Ballistic Missile," U. S. Navy Ordnance Specification OS-10707, Issue 3 (Development), 27 Dec 1961 (UNCL).

2. Rogel, A. P., and Schoner, F. X., "Phase I - Silver-Infiltrated Tungsten Round Robin Program," Aerojet-General Corporation, Sacramento, California, 5 July 1962 (UNCL).

3. Sinclair, K. F., and Hitchcock, G. W., "Dynamic Flaw Detection Using Penetrating Radiation and Scintillation Detection," USNRDL-TR-534, Oct 1961 (UNCL).

4. Sinclair, K. F., and Zagorites, H. A., "Dynamic Radiological Testing Method," presented at the ARS Solid Propellant Rocket Conference, 24-27 Jan 1962, Baylor University, Waco, Texas (UNCL).

5. Wolicki, E. A., Jastrow, R., and Brooks, F., "Calculated Efficiencies of NaI Crystals," NRL report 4833, 5 Oct 1965 (UNCL).

6. "Radiological Health Handbook," U. S. Department of Health, Education, and Welfare document PB 121784, Jan 1957 (UNCL).

7. Aerojet-General, Inc. ltr SRP:6000:1910:saj, P-5819 to Bureau of Naval Weapons Representative (SPL-40), Sunnyvale, California, dated 1 June 1962.

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51	CG, USA CBR Agency
52	President, Chemical Corps Board

53	CO, Chemical Corps Training Command
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56	CO, Chemical Research and Development Laboratories
57	Commander, Chemical Corps Nuclear Defense Laboratory
58	CO, Army Environmental Hygiene Agency
59	CG, Aberdeen Proving Ground
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63	Hq., Dugway Proving Ground
64-66	The Surgeon General (MEDNE)
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68	CG, Engineer Res. and Dev. Laboratory
69	Director, Office of Special Weapons Development
70	CO, Watertown Arsenal
71	CG, Mobility Command
72	CG, Munitions Command
73	CO, Frankford Arsenal
74	CG, Army Missile Command

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99	Commander, FC/DASA, Sandia Base (FCWT)
100-101	Office of Civil Defense, Washington
102-103	Civil Defense Unit, Army Library
104-113	Armed Services Technical Information Agency
114	Director, Armed Forces Radiobiology Research Institute

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120	Allis-Chalmers Manufacturing Co., Washington
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